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THE ROLES OF MODELS IN THE FOREST RESPONSE PROGRAM

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ABSTRACT. The Forest Response Program is a US Environmental Protection Agency and US Forest Service interagency research program on the effects of acidic deposition ("acid rain") on trees and forests. The program plans to use a diversity of models to accomplish several goals. Two primary goals are to understand the effects of sulfur and nitrogen deposition on trees and forests and to be able to predict the response of trees and forests to alternative deposition scenarios.

Achieving these goals will require many modeling efforts along the way. Modeling is used extensively in planning. Early model analysis helps to determine further needed empirical work. In addition, qualitative analysis of the models themselves (through loop analysis) will help to determine which models or aspects of models require further detailed attention. This approach focuses the modeling effort and avoids unnecessary modeling which is not needed for the Program.

A major aspect of the modeling effort within the Program is to understand the ways in which the many models and their roles fit together. Here, several ways of classifying models are presented. A scheme using biological levels of organization is presented as the backbone of the modeling effort. In particular, whole tree physiology-based models of individuals trees will be integrated into individual-tree stand models. The emphasis is on a modeling system and we resolve the generality, realty, and precision dilemma in favor of generality and reality.

INTRODUCTION

THE PURPOSE OF THIS PAPER

Both "roles" and "models" are intentionally plural in the title of this paper. The Forest Response Program (FRP) must use a variety of models and modeling efforts to achieve its goals. The purpose of this paper is to give an account of the diversity of models that will be used in the FRP and then to show how this diversity will be structured or organized to make it useful. It is one thing to say that a program will use a variety of models and another to ensure that a "sack of doorknobs" does not result.

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BACKGROUND ON THE FOREST RESPONSE PROGRAM

The Forest Response Program is an interagency program of the US Environmental Protection Agency and the US Forest Service. It operates as part of the National Acid Precipitation Assessment Program (NAPAP). The goal of the FRP is to answer three policy questions (see Table 1) about the effects of acid precipitation and associated pollutants on trees and forests. The FRP intends to answer these questions by producing five Major Program Outputs between now and 1991 (see Table 2).

Policy Question 1: Is there a significant problem of forest damage in North America which might be caused by acidic deposition, alone or in combination with other pollutants?
Policy Question 2: If so, what is the causal relationship between acidic deposition, alone or in combination with other pollutants, and forest damage in North America?
Policy Question 3: If there is a causal relationship, what is the dose-response relationship between acidic deposition, alone or in combination with other pollutants, and forest damage in North America?

Table 1. Forest Response Program Policy Questions

1. Evaluation of the extent and magnitude of recent changes in forest condition (12/88).
2. Evaluation of the role of non-air pollution factors in growth reduction and visible decline (12/88).
3. Quantitative estimates of seedling responses to S, N, and associated pollutants at ambient conditions (2/88 and annually).
4. Evaluation of the roles of S, N, and associated pollutants in forest decline (4/89, 4/91).
5. Projection of responses under alternative deposition scenarios (12/91).

Table 2. The Major Program Outputs and their expected completion dates.

THE STRUCTURE OF THIS PAPER

I will describe four ways that models can be classified in an attempt to describe both the diversity of models and modeling approaches that the FRP will use and to highlight several of the trade-offs that must be considered in choosing between various modeling methods and styles. This will be followed by an overall conceptual framework which attempts to organize the modeling and data analysis efforts into a conceptually coherent whole. I will then discuss an example area of modeling that raises specific issues about which the program is concerned.

CLASSIFICATIONS OF MODELS

Models are tools and may be classified in a great variety of ways. Just as the tools of the carpenter and the tools of the printer are organized differently, so can the many types of models used by biologists working with trees and forests.

CENTRALITY OF MANAGEMENT

In a large program, models may be classified by the degree of control that the central management of the program might want to exercise. Some programs have considered all models the same in this respect, either exerting no control over the models or attempting to produce only a single centrally managed model. The FRP recognizes that management interacts with the modeling effort in diverse ways. A classification on this basis is the following.

1. Research Tool Models. These are models developed by Principal Investigators (PIs) as their research progresses for any reason whatever and in any style. Their job is to help the PI. Such models attract little or no interest from central management, except as sources of information.

2. Local Expert Models. These are larger, usually complex models that represent the accumulation of a great deal of information and work on the part of the forestry community which apply to a given species or region. The well-known growth and yield models such as STEMS, PTAEDA, and PROGNOSIS (to mention only a few) are examples of this type of model. These models can be used as important components of a research program to identify pollution effects. For example, data on growth and natural environmental variables can be fitted to these models and the residuals examined for possible associations with pollution. In the case of local expert models, central management may be more interested in the models because of their importance in the overall program. Although these models are used more or less "off-the-shelf," central management is further concerned that two aspects are developed as appropriate to the given model. The first is that the assumed mechanism of action of pollution in the models be specified explicitly if possible. (It may not be possible; pollution may reside in the error term). The second concern is that estimates of confidence intervals on the projects of the model be given. In the context of the FRP, confidence intervals are at least as important as the projections themselves. This is not a trivial requirement in most cases. Many local expert models have taken a great deal of time and effort just to get to the point of making projections. Adding confidence interval estimates is almost as large a task. Nonetheless, they are critical for a model that is to be used in this Program.

3. Synthesis Models. These are models constructed with close guidance from central management to synthesize the information gathered across the entire Program into the Major Program Outputs. However, even though these models are centrally managed, it is important to realize that the goal here is a modeling system, not a single model. This spirit of modeling dovetails

with modern software engineering concepts (see Brooks, 1979, for the management issues). Implementation is done via the construction of libraries of small modules of computer code which are designed to be useful in a large variety of situations. The computer language chosen to implement such modeling systems must encourage such an approach.

Synthesis models may therefore start life as box-and-arrow diagrams. Each box can then become a module in a simulation model. At first, the contents of the box can be a constant, later a function or complex simulation in itself. The overall model assembled from the parts should not depend upon the detail actually in the boxes.

The modular approach also makes it possible for work to be done on the modeling system at many locations by many different groups. Although centrally managed, the actual coding effort can be distributed if attention is paid to careful programming management.

The modular approach also makes it easier to provide Quality Assurance and Quality Control (QA/QC) for the actual code that makes up the models. Because each module is tested separately and stored in the library with a test driver, QA/QC can be made a routine part of the effort. A Source Code Control System (see, for example, Kernighan and Pike, 1984) coupled with a library manager can automate this process.

GENERALITY, REALITY, AND PRECISION

Levins (1966; see also Puccia and Levins, 1985) has introduced a useful classification of models in population biology which also applies to the models to be used by the FRP. Levins claims that modelers try to simultaneously maximize three desired properties of a given model: generality, reality, and precision. He then argues that any one model sacrifices one of these desired properties to achieve more of the other two. The argument is based on an analysis of a number of models used in population biology. Models are therefore classified by which property is sacrificed for the other two.

In traditional growth and yield models it is fair to say that generality is sacrificed for increased reality and especially precision. If the goal of the model is to predict yield on a specific plot at a specific time this is, of course, the best strategy to take.

For the purposes of the FRP synthesis models, however, a different trade-off is needed: The FRP must emphasize generality and reality at the expense of precision. The Policy Questions which drive the Program require answers at a level of generality that is greater than is required by a specific growth and yield question. The importance placed by the Program on an understanding of the physiological mechanism of action of a pollutant dictates that reality must be maximized in the models as well. Therefore, precision will have to be sacrificed. It is

important to realize that these trade-offs are not black-and-white for the synthesis models, and that for the research tool and local expert models other choices may be made.

BIOLOGICAL LEVELS OF ORGANIZATION

Work within the FRP occurs at many levels of biological organization. Models as well may be classified by the level of organization to which they apply. The FRP distinguishes four levels of organization in its modeling efforts: seedling physiology (growth); whole (mature) tree physiology (growth and mortality); stand growth and yield; and regional growth and yield. Models may either apply to a single level of organization or may serve to link two levels of organization. For example, much of the experimental work in the Program is conducted on seedlings for obvious practical reasons. But it is important that the connection between seedling physiology and mature tree physiology be made. Although this is an outstandingly difficult problem, models may help.

The four levels of organization chosen represent the results of decisions to focus the scope of the Program. Both subcellular processes in the sense of specific biochemical pathways and community level processes such as the maintenance of diversity are left out. These may be addressed by Research Tool Models or may be brought into the Synthesis Models if necessary. The biological levels of organization approach also does not include effects on trees and forests which are not biological such as recreational use and esthetics. These are not included because the Program must focus on biological research.

RADIUS OF INFORMATION

An important dichotomy in modeling has to do with the work a model is being asked to do. Models may be used to either make quantitative projections or to summarize our current understanding of how the world works. While this dichotomy has value in helping to understand the diversity of models, it is also true that most models are a mixture. The nature of this mixture is important when a modeler is faced with "extrapolating beyond the data." If one is restricted to empirical (or, as they are commonly called, statistical) models, then extrapolating beyond the data is difficult or impossible. Physiological process models are not as good at quantitative projection but may expand the range over which projections may be made. Figure 1 illustrates this for an arbitrary parameter p (which could be a measure of acidic deposition) and a response function f (which could be the growth response of a stand). The modeler will have direct data on p and f for a limited range of values of p. Over this range an empirical model is possible. However, extension of the modeling effort to include a process-based model as well may extend the range over which f may be understood. Figure 1 shows the unfortunate case where the region of interest is still greater than we can cover in the mixed modeling effort (this could be the case if future more extreme values of deposition needed to be

considered). Figure 2 shows the fortunate case where the mixture will allow examination of the entire range of interest. In general the region of interest is not known at the outset of a research program so methods for expanding the range must be at hand.

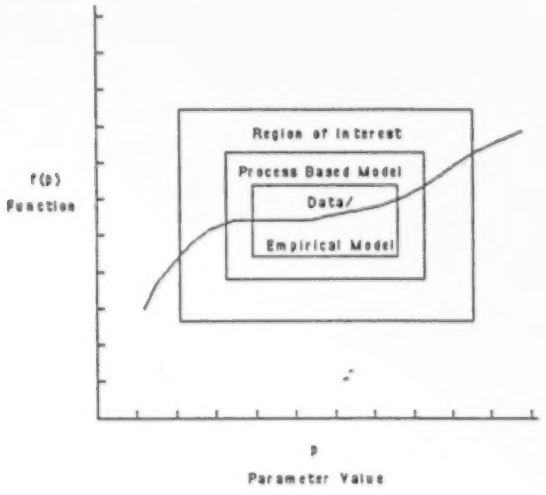

Figure 1.

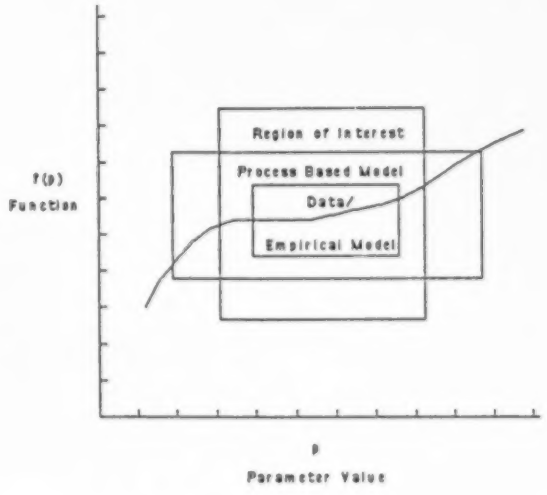

Figure 2.

STRUCTURING THE DIVERSITY OF MODELS

PLANNING FOR MODELING

In a program such as the FRP planning for the modeling effort is an integral component of the overall planning activity. Modeling tasks must be identified and resources allocated to them. The uses of particular models must be specified. It is important to plan for flexibility since requirements may change as our understanding of the science improves or as the questions of the policy makers change.

MODELING FOR PLANNING

Relatively simple models are important at early stages of the Program to aid in planning research. Models are needed to identify missing data and also to give ideas on the type and amount of data that may be needed to answer a question. Models do not constitute the only method of planning, however. Information of many kinds must feed into the planning process.

QUALITATIVE AND SENSITIVITY ANALYSES

Early versions of models of the box-and-arrow type may be subjected to qualitative analysis. Even if the internal structure of the boxes is poorly specified, important information may be gained by analyzing the interactions of the components themselves (Levins, 1974). One technique is loop analysis (Levins, 1974;

Puccia and Levins, 1985). Here the relative importance of each box or arrow in the model can be determined. This method is potentially valuable as a planning exercise in that it can suggest which boxes should have their details filled in first. This could help to focus the modeling effort and avoid modeling that is not necessary. Loop analysis is only one method of sensitivity analysis. Other, more sophisticated, methods can be developed for more complex models (see Makela, this volume)

VALIDATION AND INTER-MODEL COMPARISON

Along with the diversity of models considered by the FRP are a corresponding diversity of methods of validation. Naturally, empirical models will have to be validated by data sets similar to those from which the models were created. However, process-based and mixed models may be validated in other ways such as by reference to particular experimental results. That is, the models may be validated by validating their assumptions. Other models will not be validated directly, but will need to be subjected to Monte Carlo methods to determine the range of possibly valid results. Another technique may be to compare model outputs. A stand model which contains components of a process-based physiology model may be partially validated by comparing its output, say the diameter distribution, to the patterns generated by an empirical model.

Comparison of models is also an important research task. For example, the Local Expert Models all predict changes in stand productivity based on changes in individual tree growth. These various predictions of the different models which apply to different species in different regions need to be compared. The Program needs a methodology for making such comparisons in a quantitative fashion.

STAND DYNAMICS AS THE PIVOT

Although the FRP is concerned with several levels of biological organization, there is a sense in which the level of stand dynamics is the most important. The internal processes of tree physiology and the external processes of the environment meet at the level of the stand. Trees in stands do not behave like individual trees. In particular trees under stress (as from pollution) in stands do not behave the same as isolated trees under stress. Hyink and Zedaker (1987) have emphasized the role of stand dynamics in simply detecting decline of forests and their arguments applied with even more force to unraveling pollution caused forest decline. Normal stand dynamics is the background against which any pollution effect is set.

Hyink and Zedaker (1987) argue that the complex interplay between the genotypes of the trees, the environment, and the genotype-environment interaction must be understood before pollution effects (or any other) can be understood. This genetic view of stand dynamics is valuable, but a demographic view of stand dynamics is needed as well. In the demographic view, the parameters of birth rate, mortality rate, and growth rate depend

on the environment and on the competitive interactions of the trees. Of course these parameters depend on the genetic constitution of the trees, but we frequently do not have that information. Also a single model cannot usually contain genetic richness as well as complex environmental dynamics. However, whether the genetic or demographic view is used, the important point is that trees, stands, and their environments are constantly changing. Pollution effects can only be understood in the context of normal dynamics.

DISCUSSION

Competition may be taken as an example of the complexities of modeling in a program such as the FRP. First, competition is clearly an important component of stand dynamics. However, it is also true that competition takes place at the level of individual tree physiological processes. Individual trees compete for light or nutrients or water uptake and these processes must be modeled at a physiological level. Competition undoubtedly will appear in models that fall in all of the categories of all of the classifications. The job of the Forest Response Program is to make the best use of all of the approaches to modeling competition or any other aspect of trees and forests as they are effected by acid deposition.

This is not an easy task but we have a good chance of succeeding for two reasons. First, the Program is attempting to build on the tremendous amount of relevant work that has preceded it. Second, by adopting a distributed, team, approach to the synthesis models, the Program can utilize the talents of many people.

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